J. Phys. E: Sci. Instrum., Vol. 14, 1981. Printed in Great Britain

# Laser pulse selection with krytron triggered Kerr shutter

**A Penzkofer, S Weinmann and J Biebl**
Naturwissenschaftliche Fakultät II–Physik, Universität Regensburg, 8400 Regensburg, Germany

*Received 23 March 1981, in final form 8 June 1981*

**Abstract** A 16 kV krytron pulse generator and a 30 kV krytron activated spark gap are developed to operate a Kerr cell shutter. The shutter is used to select single picosecond light pulses from a mode locked laser and to separate nanosecond light signals from a free running laser.

## 1 Introduction

The selection of single picosecond light pulses from mode locked lasers is performed with Pockels cell or Kerr cell shutters. Pockels cell switching devices (half wave voltage $V_{\lambda/2} \simeq 4$ to 6 kV) are operated by laser triggered spark gaps (Morgan and Peacock 1971, Alcock and Richardson 1970), krytrons (Hyer *et al* 1975, Billman and Burnham 1970, Ley *et al* 1970, Hyde *et al* 1977, Scott *et al* 1976, Pearce and McLead 1977), avalanche circuits (Davis *et al* 1978, Brasseur *et al* 1975) and planar triodes (Martin *et al* 1979, Davis and Gagnon 1980). Kerr cell switches have a high half wave voltage ($V_{\lambda/2} = 10$ to 20 kV) and have only been used with laser triggered spark gaps (Von der Linde *et al* 1970, De Maria *et al* 1967). Semiconductor triggered Pockels and Kerr cell shutters are not applicable to pulse switching from mode locked or free running lasers since a single short (subnanosecond) light pulse is needed for reliable switching the semiconductor to the conductive state (Auston 1975, Lee 1977, Antonetti *et al* 1977, Mourou *et al* 1980).

In this paper a 16 kV krytron system and a 30 kV krytron activated spark gap system are described. The pulse generators are used to operate a Kerr cell shutter for the selection of single picosecond light pulses from a mode locked Nd–glass laser and for the separation of nanosecond pulses from a free running Nd–glass laser.

Kerr cell shutters yield higher blocking ratios ($\approx 10000$) than Pockels cell shutters ($\approx 1000$). The operation of Kerr cells with krytron pulse generators or krytron triggered spark gaps allows pulse selection at adjustable time positions. The amplitude fluctuation of the separated pulses is reduced to a few per cent. A synchronisation pulse generated in the krytron system is available for synchronisation of further switches and gating of detection systems (Biebl and Penzkofer 1980).

## 2 Krytron pulse generator

The krytron pulse generator consists of a trigger section, an avalanche transistor chain, two krytrons in series with high voltage charging facility and a pretrigger unit.

The circuit of the trigger section and the avalanche chain is described in a previous report (Biebl and Penzkofer 1980) and is only slightly modified ($R_8 = R_6 = 0$, $R_5 = 1\ \Omega$; a capacitor of 2.2 nF is added parallel to $R_{11}$). The krytron stage and the pretrigger section are shown in figure 1(*a*). Two krytrons KN22B (EG&G Electro-optics division data sheet K 550 B-2) in series are used (EG&G application note K550313-A, for high-voltage krytron systems see also Lippitsch *et al* 1978). The self-breakdown threshold of the krytrons is $>8$ kV. A

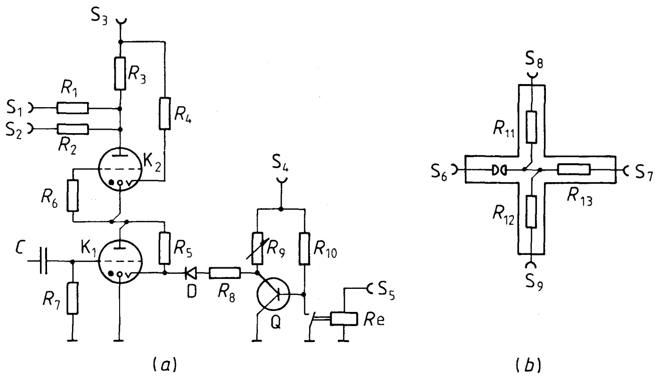


**Figure 1** (*a*) Krytron pulse generator. Trigger section and avalanche chain is omitted. Resistors: $R_1 = R_2 = 45\ \Omega$, $R_3 = 40\ \mathrm{M\Omega}$, $R_4 = R_5 = 24\ \mathrm{M\Omega}$, $R_6 = R_7 = 1\ \mathrm{M\Omega}$, $R_8 = 220\ \mathrm{k\Omega}$, $R_9 = 175\ \mathrm{k\Omega}$, $R_{10} = 100\ \mathrm{k\Omega}$. Capacitor: $C = 500$ pF (6 kV). Krytrons: $K_1$ and $K_2$, KN22B (EG&G). Diode: D, 5AV60 (International Rectifier). Transistor: Q, BF459 (Siemens). Reed relay: Re (trigger threshold 1.5 V).
(*b*) Spark gap. Resistors: $R_{11} = R_{12} = 50\ \Omega$, $R_{13} = 200\ \mathrm{M\Omega}$.

bias voltage $V_K$ of up to 16 kV is applied at $S_3$. It charges two 50 Ω coaxial cables $L_1$ and $L_2$ which are connected to the krytron system at $S_1$ and $S_2$. The keep-alive current for the krytrons ($\simeq 300\ \mu$A) is derived from $V_K$ with resistors $R_4$ and $R_5$. The krytrons are fired with a pulse from the avalanche chain via capacitor $C$. Before triggering the krytrons the keep-alive current through krytron $K_1$ is increased to about 600 $\mu$A for a duration of 1 ms by switching off transistor Q with relay Re. A voltage of $V_P \simeq 300$ V is applied to this pretrigger system at $S_4$ (see Cunin *et al* 1980).

When the krytrons are fired at time $t = 0$ to the conductive state, the pulse forming cables $L_1$ and $L_2$ are discharged and a voltage pulse of $V = V_K$ is generated between the ends of the cables starting at $t = l_1/v$ and lasting for a duration $\Delta t = (l_2 - l_1)/v$ ($l_1$, $l_2$, cable lengths, $v \simeq 0.66c \simeq 200$ mm ns$^{-1}$ signal velocity). The resistors $R_1$ and $R_2$ are adjusted to optimum impedance matching to avoid voltage reflections.

For the krytron triggered Kerr cell system the cables $L_1$ and $L_2$ are connected to the electrodes of the Kerr cell. In the krytron activated spark gap only cable $L_1$ is used for firing the spark gap.

## 3 Krytron activated spark gap

The spark gap is shown schematically in figure 1(*b*). The distance between the two brass electrodes is about 1 mm. The self-breakdown threshold voltage $V_B$ is regulated with pressurised nitrogen gas. The spark gap is connected to the krytron system by line $L_1$ (between $S_1$ and $S_6$). A high voltage $V_S$ of up to 30 kV is applied at $S_7$. The pulse forming cables

0022-3735/81/121411+04 $01.50 © 1981 The Institute of Physics

$L_1'$ and $L_2'$ are attached at $S_8$ and $S_9$ and connected to the electrodes of the Kerr cell. The voltage across the spark gap electrodes $V_S - V_K$ is chosen slightly below the self-breakdown threshold $V_B$. When the krytron system is triggered the voltage at $S_6$ drops to zero and the spark gap fires immediately ($V_S \gg V_B$). The cables $L_1'$ and $L_2'$ are discharged and produce a voltage pulse of $V = V_S$ for a duration of $\Delta t = (l_2' - l_1')/v$ at the Kerr cell. The spark gap is recharged via resistor $R_{13}$. The applied operation principle is different from two-electrode laser triggered spark gaps (Bettis and Guenther 1970, Alcock *et al* 1970, Milam *et al* 1972, Deutsch 1968, Bradley *et al* 1969, Von der Linde *et al* 1970) and three-electrode systems triggered by a high voltage pulses (Kukhta and Logachev 1976, Pulsar associates application note P-0377, 1977).

## 4 Experimental setup

The performance of the Kerr cell shutter was tested with a Nd–glass laser in mode locked (with saturable dye) and free running mode (without saturable dye). The experimental setup is shown in figure 2. A beam splitter reflects a small part of laser light to photodetector PD1 which triggers the high voltage pulse generator PG (krytron system or krytron–spark gap system). The pretrigger relay is activated by a pulse generator PPG which is synchronised to the laser control unit LCU.

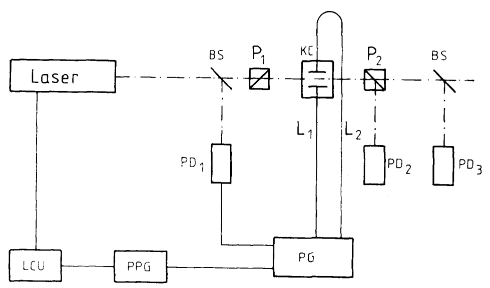


**Figure 2** Experimental setup. BS, beam splitters; $P_1$, $P_2$ glan polarisers; KC, Kerr cell; PD1–PD3 photodetectors; $L_1$, $L_2$ pulse forming cables; LCU, laser control unit; PPG, pulse generator; PG, krytron pulse generator or krytron–spark gap system.

The glan polarisers $P_1$ and $P_2$ are crossed and the laser light is directed to photodetector PD2. The high voltage pulse from the krytron or krytron–spark gap system changes the polarisation of the input light and polariser $P_2$ transmits light to detector PD3.

## 5 Performance of pulse selection

Figure 3(*a*) depicts a light signal which is selected from the free running laser with the krytron triggered Kerr shutter. The difference length of the cables was $\Delta l = l_2 - l_1 = 1.7$ m. A voltage of $V_K = 16$ kV was applied to the krytron system for complete pulse switching. The separated pulse has a half width of 10 ns. Its width at one tenth of peak height is 15 ns.

A shorter pulse of 6 ns half width and 10 ns width at one tenth of peak height was selected with the krytron–spark gap triggered Kerr shutter as shown in figure 3(*b*). The same cable difference of $\Delta l = 1.7$ m was used. The optimum voltage at the spark gap increased to $V_S \simeq 26$ kV. The krytron voltage was adjusted to $V_K = 14$ kV. The spark gap was pressurised up to 0.8 MPa (8 bar) and the self-breakdown voltage was $V_B = 12$ kV.

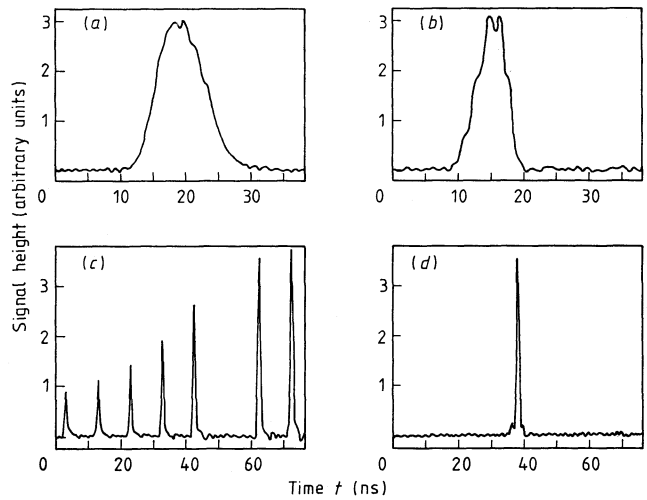


**Figure 3** Pulse shapes. (*a*) Signal selected from free running laser with krytron triggered Kerr shutter. Cable difference $\Delta l = 1.7$ m; voltage $V_K = 16$ kV. (*b*) Pulse selected with krytron–spark gap triggered Kerr system. $\Delta l = 1.7$ m, $p = 0.7$ MPa (7 bar), $V_K = 14$ kV, $V_S = 25$ kV. (*c*) Mode locked pulse train detected with photocell PD2. Krytron–Kerr shutter is used. $\Delta l = 1.7$ m; $V_K = 16$ kV. (*d*) Single picosecond pulse separated with krytron triggered Kerr shutter.

Figure 3(*c*) shows a mode-locked pulse train where one pulse was selected with the krytron–Kerr cell shutter (krytron parameters as in figure 3(*a*)). A selected single picosecond pulse is seen in figure 3(*d*).

The light transmission through the Kerr shutter is depicted in figure 4. The solid curve is calculated from the theoretical

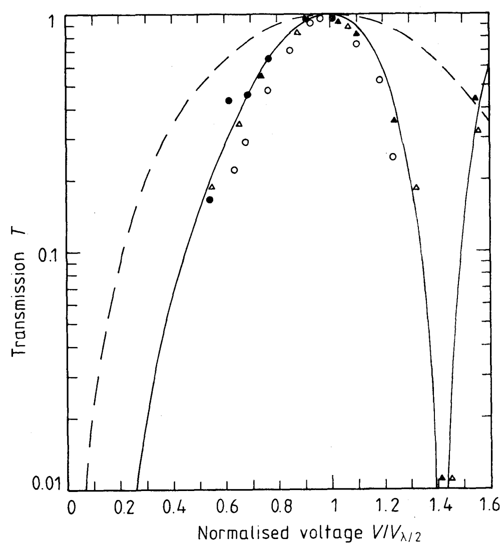


**Figure 4** Light transmission through shutter. Full curve, calculated for Kerr shutter. Broken curve, calculated for Pockels cell switch. ○, krytron triggered Kerr cell with $\Delta l = 2.8$ m ($V_{\lambda/2} = 11.7$ kV); △, steady state transmission through krytron-Kerr cell system ($\Delta l = 18$ m, $V_{\lambda/2} = 9$ kV); ●, transient peak transmission through krytron–spark gap Kerr cell system with $\Delta l = 1.7$ m ($V_{\lambda/2} = 26$ kV); ▲, steady state transmission through krytron-spark gap activated Kerr system ($\Delta l = 18$ m, $V_{\lambda/2} = 13.4$ kV).

relation $T = \sin^2 [(V/V_{\lambda/2})^2 \pi/2]$. The open circles ($\Delta l = 2.8$ m $V_{\lambda/2} = 11.7$ kV) and triangles ($\Delta l = 18$ m, $V_{\lambda/2} = 9$ kV) were measured with the krytron triggered Kerr system. The closed circles ($\Delta l = 1.7$ m, $V_{\lambda/2} = 26$ kV) and triangles ($\Delta l = 18$ m, $V_{\lambda/2} = 13.4$ kV) were obtained with the krytron–spark gap Kerr shutter. The transmission $T(V/V_{\lambda/2})$ was found to be independent of $\Delta l$. The dashed line of figure 4 shows the theoretical transmission of a Pockels cell shutter ($T = \sin^2 [\pi V/(2V_{\lambda/2})]$). A comparison of the transmission curves indicates that weak voltage pulses (e.g. from cable reflections) open the Kerr cell shutter less than a Pockels cell shutter.

The optimum switching voltage $V_{\lambda/2}$ depends on the difference of the cable length $\Delta l$ as shown in figure 5(*a*). For large values of $\Delta l$, $V_{\lambda/2}$ reduces to a steady state value of 9 kV in case of the krytron–Kerr cell system and 13.4 kV for the krytron–spark gap–Kerr cell system (distance between Kerr plates 3.5 mm, length of Kerr electrodes 40 mm).

The half widths and 1/10-widths of the pulses separated from the free running laser are shown in figure 5(*b*). The krytron–spark gap triggered Kerr shutter gives shorter pulse widths than the krytron triggered device.

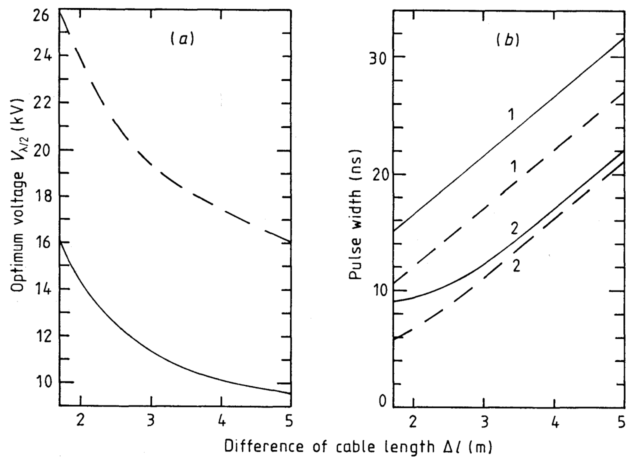


**Figure 5** Experimental optimum switching voltage (*a*) and pulse widths (*b*) against difference length of charging cables. Full curves, krytron triggered Kerr shutter. Broken curves, krytron-spark gap triggered Kerr cell system. 1, pulse width at one tenth of peak height; 2, half width.

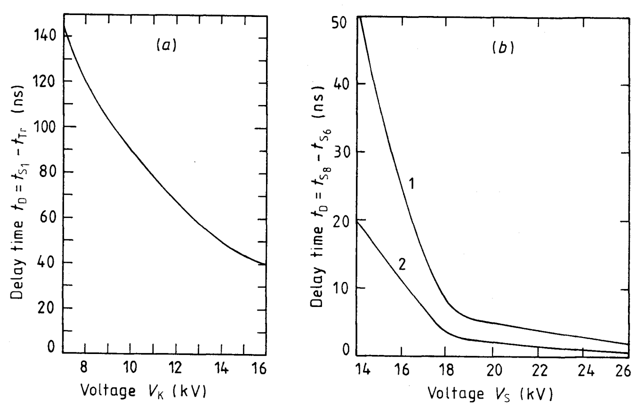


**Figure 6** Delay times. (*a*) Krytron system. Measured delay time between onset of cable discharge and input trigger signal. (*b*) Spark gap. Time delay between cable discharge and voltage drop at input electrode. 1, nitrogen pressure $p = 0.6$ MPa (6 bar), self-breakdown voltage $V_B = 12$ kV, krytron voltage $V_K = 14$ kV. 2, $p = 0.8$ MPa (8 bar), $V_B = 12$ kV, $V_K = 14$ kV.

The time delay between signal output at the high voltage pulse generators and the trigger input is analysed in figure 6. The time difference $t_D = t_{S1} - t_{Tr}$ between onset of cable decharging $t_{S1}$ and the leading edge of the trigger signal at the trigger input $t_{Tr}$ is plotted in figure 6(*a*). The standard deviation of the delay (jitter) was 1.5 ns at $V_K = 16$ kV and increased to 2.5 ns at $V_K = 9$ kV. Without pretrigger the delay increased by 10 ns and a jitter of 3 ns was measured at $V_K = 16$ kV. The time delay in the trigger transistor and avalanche chain was 11 ns.

The time delay between firing the spark gap and removal of voltage at $S_6$, $t_D = t_{S8} - t_{S6}$, depends on the charging voltage $V_S$, on the nitrogen pressure $p$ and the self-breakdown threshold $V_B$. Two curves are presented in figure 6(*b*). For pressure $p < 0.5$ MPa (5 bar) the spark gap operates unreliably. The jitter of the complete krytron–spark gap system was 2.5 ns for $V_S \geqslant 20$ kV, $V_K = 14$ kV, $p = 0.6$–$0.8$ MPa (6 to 8 bar) and $V_B = 10$ to 13 kV (see also Kukhta and Logachev 1976).

The switching position is easily varied with filters in the detector PD1. In the free running laser mode the signal height at the switching position fluctuated by 1.5% for both the krytron and krytron–spark gap Kerr shutter. In the mode locked case the height of the selected pulses varied by about 10%, when pulses were selected in the rising part of the pulse train. This pulse height selective switching results in a well defined switching position. Slight changes of the switching position occur due to variations in the shape of the pulse trains.

Outside the switching region the light transmission through the Kerr shutter was about $1.6 \times 10^{-4}$. The transmission of the picosecond pulse following the switched pulse is about 1% in the case of the krytron–spark gap Kerr shutter and about 5% in the case of the krytron–Kerr system (pulse separation is 10 ns). The light transmission through the shutter due to voltage reflections of the charging cables is about 2% in both systems.

The pulse selection was performed at a repetition rate of 0.1 Hz. The repetition rate is limited by recharging of the pulse forming cables and the recovery of the krytrons (EG&G data sheet K5500 B-2) and spark gap (EG&G data sheet G6000 E-1). A rate of up to 50 Hz should be possible.

**Acknowledgments**
The authors thank G Gössl for valuable discussions on the electronic circuit and T Ascherl for technical assistance.

**References**

Alcock A J and Richardson M C 1970 Production of subnanosecond light pulses with the aid of a laser-triggered spark gap
*Opt. Comm.* **2** 65–8

Alcock A J, Richardson M C and Leopold K 1970 A simple laser-triggered spark gap with subnanosecond risetime
*Rev. Sci. Instrum.* **41** 1028–9

Antonetti A, Malley M M, Mourou G and Orszag A 1977 High power switching with picosecond precision: applications to high speed Kerr cell and Pockels cell
*Opt. Comm.* **23** 435–9

Auston D H 1975 Picosecond optoelectronic switching and gating in silicon
*Appl. Phys. Lett.* **26** 101

Bettis J R and Guenther A H 1970 Subnanosecond-jitter laser-triggered switching at moderate repetition rates
*IEEE J. Quant. Electron.* **QE-6** 483–91

Biebl J and Penzkofer A 1980 Gating of optical multichannel analysers with krytron switches
*J. Phys. E: Sci. Instrum.* **13** 1328–30

Billman K W and Burnham D C 1970 Photodetector triggered pulse selection from a mode locked ruby laser
*Rev. Sci. Instrum.* **41** 1837–8

Bradley D J, Higgins J F, Key M H and Majumdar S 1969 A simple laser-triggered spark gap for kilovolt pulses of accurately variable timing
*Opto-Electron.* **1** 62–4

Brasseur G, Van Eck J L and Vilain P 1975 Selection of a single pulse from a mode-locked laser using avalanche transistors
*Appl. Opt.* **14** 1758–9

Cunin B, Miehe J A, Sipp B, Schelev M Ya, Serduchenko J N and Thebault J 1980 Sweep devices for picosecond image-converter streak cameras
*Rev. Sci. Instrum.* **51** 103–10

Davis J S, Murray J E, Downs D C and Lowdermilk W H 1978 High performance avalanche-transistor switchout for external pulse selection at 1.06 $\mu$m
*Appl. Opt.* **17** 3184–6

Davis J S and Gagnon W L 1980 Fast pulse development Laser program annual report – 1979 Lawrence Livermore Laboratory, Livermore, Calif.
*UCRL*-50021–79 pp 2.232–2.234

De Maria A J, Gagosz R, Heynau H A, Penney A W Jr and Wisner G 1967 Generation and amplification of a subnanosecond laser pulse
*J. Appl. Phys.* **38** 2693–5

Deutsch F 1968 Triggering of a pressurized spark gap by a laser beam
*J. Phys. D: Appl. Phys.* **1** 1711–9

Hyde R L, Jacoby D and Ramsden S A 1977 A laser-triggered krytron-Blumlein electro-optic switch
*J. Phys. E: Sci. Instrum.* **10** 1106–7

Hyer R C, Sutphin H D and Winn K R 1975 Laser-initiated krytron-switched Blumlein structure for pulse selection
*Rev. Sci. Instrum.* **46** 1333–4

Kukhta V R and Logachev E I 1976 Controlled spark gaps for high-voltage pulse generators
*Instrum. Exp. Techn.* **6** 1670–3

Lee C H 1977 Picosecond optoelectronic switching in GaAs
*Appl. Phys. Lett.* **30** 84

Ley J M, Cristmas T M and Wildey C G 1970 Solid-state subnanosecond light switch
*Proc. IEE* **117** 1057–62

Lippitsch M E, Möller R, Noll H M, Schiefer E and Aussenegg F R 1978 A 20 kV, nanosecond-rise-time pulse generator using krytrons
*J. Phys. E: Sci. Instrum.* **11** 621–2

Martin W E, Howland M M and Davis J S 1979 Large-aperture Pockels cells for system isolation Laser program annual report – 1978, Lawrence Livermore Laboratory, Livermore, Calif.
*UCRL*-50021–78 pp 7.29–7.34

Milam D, Gallagher C C, Bradbury R A and Bliss E S 1972 Switching jitter in spark gap triggered by a $TEM_{00}$-mode mode-locked ruby laser
*Rev. Sci. Instrum.* **43** 1482–4

Morgan P D and Peacock N J 1971 Nanosecond laser pulse generation using an electro-optic shutter external to the *Q*-spoiled cavity
*J. Phys. E: Sci. Instrum.* **10** 677–80

Mourou G, Knox W and Stavola M 1980 Optoelectronic switching in the picosecond time domain and its application
*Picosecond Phenomena II* ed R M Hochstrasser, W Kaiser and C V Shank
*Springer Series in Chemical Physics* vol 14 (Berlin:Springer) p 75

Pearce I K and McLead D D 1977 Externally self-modulated laser producing two pulses
*J. Phys. E: Sci. Instrum.* **10** 961–2

Scott J C, Ley J and Palmer A W 1976 A simple switching system for producing single and double variably spaced, variable length nanosecond light pulses
*Opt. Quant. Electr.* **8** 561–3

Von der Linde D, Bernecker O and Laubereau A 1970 A fast electro-optic shutter for the selection of single picosecond laser pulses
*Opt. Comm.* **2** 215–8